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A light-front description of electromagnetic form factors for $J \leq \frac{3}{2}$ hadrons

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A review of the hadron electromagnetic form factors obtained in a light-front constituent quark model, based on the eigenfunctions of a mass operator, is presented. The relevance of different components in the q-q interaction for the description of hadron experimental form factors is analysed.

1. INTRODUCTION

Within a relativistic light-front (LF) constituent-quark (CQ) model, we performed an extended investigation of elastic and transition electromagnetic (e.m.) hadron form factors [1] in the momentum transfer region relevant for the experimental research programme at TJNAF [2]. The main features of the model are: i) eigenstates of a mass operator which reproduces a large part of the hadron spectrum; ii) a one-body current operator with phenomenological Dirac and Pauli form factors for the CQ 's. The CQ 's are assumed to interact via the $q - q$ potential of Capstick and Isgur (CI) [3], which includes a linear confining term and an effective one-gluon-exchange (OGE) term. The latter produces a huge amount of high-momentum components in the baryon wave functions [1] and contains a central Coulomb-like potential, a spin-dependent part, responsible for the hyperfine splitting of baryon masses, and a tensor part. A comparable amount of high momentum components was obtained [1](f) with the $q - q$ interaction based on the exchange of the pseudoscalar Goldstone-bosons [4]. This fact suggests that the hadron spectrum itself dictates the high momentum behaviour in hadron wave functions. In this paper a review of our results for the elastic and transition form factors for $J \leq \frac{3}{2}$ hadrons is presented [1](a-g).

2. ELECTROMAGNETIC HADRON FORM FACTORS IN THE LF DYNAMICS

In the LF formalism the space-like e.m. form factors can be related to the matrix elements of the *plus* component of the e.m. current, $\mathcal{I}^+ = \mathcal{I}^0 + \mathcal{I}_z$, in the reference frame where $q^+ = q^0 + q_z = P_f^+ - P_i^+ = 0$. We have evaluated elastic and transition form factors (f.f.) by assuming the \mathcal{I}^+ component of the e.m. current to be the sum of one-body CQ currents [1], i.e. $\mathcal{I}^+(0) \approx \sum_{j=1}^3 I_j^+(0) = \sum_{j=1}^3 \left(e_j \gamma^+ f_1^j(Q^2) + i \kappa_j \frac{\sigma^{+\rho} q_\rho}{2m_j} f_2^j(Q^2) \right)$ with e_j (κ_j) the charge (anomalous magnetic moment) of the j -th quark, and $f_{1(2)}^j$ its Dirac (Pauli) form factor. We studied first pion and nucleon elastic form factors and showed that an effective one-body e.m. current, with a suitable choice for the CQ form factors, is able to give a coherent description of pion and nucleon experimental data [1](a).

In this paper our fit of the CQ form factors is updated to describe the most recent data for the nucleon f.f., in particular for the ratio $G_{Ep}\mu_p/G_{Mp}$ [5].

In Fig. 1 the elastic proton form factors are shown, in order to illustrate the high quality fit one can reach (a fit of the same quality is obtained for the neutron and the pion as well). It is interesting to note that, while effective CQ f.f. are required to describe the nucleon f.f., the experimental data for the ratio $G_{Ep}^p\mu_p/G_M^p$ can also be reproduced by the current with pointlike CQ 's (see dashed line in Fig. 1 (b)). Therefore this ratio appears to be directly linked to the structure of the nucleon wave function.

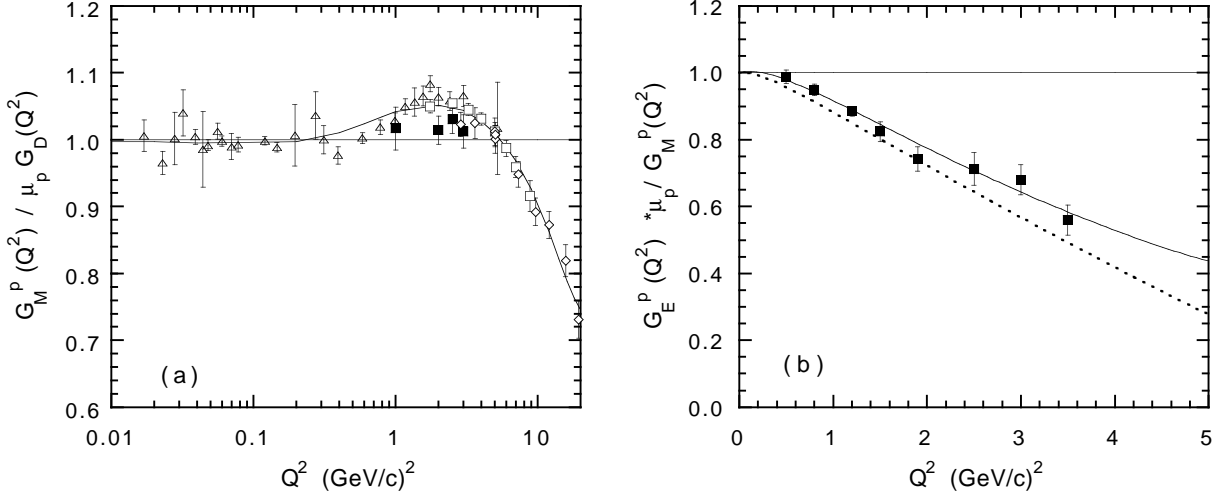


Figure 1. The proton magnetic form factor $G_M^p(Q^2)/\mu_p G_D(Q^2)$ (a), and the ratio $G_E^p(Q^2)\mu_p/G_M^p(Q^2)$ (b) vs. Q^2 ($G_D(Q^2) = (1 + Q^2/0.71)^{-2}$). In (b) the solid and dashed lines represent our results with and without CQ form factors, respectively. Experimental data in (a) are as quoted in Ref. [1](a); experimental data in (b) are from Ref. [5].

3. NUCLEON-RESONANCE TRANSITION FORM FACTORS

Once the CQ form factors have been determined, we can obtain *parameter-free* predictions for the nucleon-resonance transition form factors.

In Fig. 2 our evaluations of the helicity amplitude $A_{1/2}$ are shown for $N \rightarrow S_{11}(1535)$, $S_{11}(1650)$ and $S_{31}(1620)$, and compared with the results of a non-relativistic model [6]. In the case of $S_{31}(1620)$ the results for p and n coincide (as for $P_{33}(1232)$), since only the isovector part of the CQ current is effective. Our predictions yield an overall agreement with available experimental data for the P -wave resonances and show a sizeable sensitivity to relativistic effects, but more accurate data are needed to reliably discriminate between different models.

Our parameter-free predictions for the $N - \Delta(1232)$ transition form factors, obtained using the prescriptions i) and ii) defined in [1](d), are compared with existing data in Fig. 3 (a),(b),(c). In Fig. 3 (d) the ratio between $G_M^{N-\Delta}(Q^2)$ and the isovector part of the nucleon magnetic form factor, $G_M^p(Q^2) - G_M^n(Q^2)$, is shown to be largely insensitive to the presence of CQ form factors, whereas it is sharply affected by the spin-dependent part of the CI potential, which is generated by the chromomagnetic interaction. It can clearly be seen that: i) the effect of the tiny D -wave component ($P_D^\Delta = 1.1\%$), and then of the tensor part in the $q - q$ interaction, is small for $G_M^{N-\Delta}$, as well as for E_1/M_1 and S_1/M_1 (the $L = 0$ component gives non-zero values of E_1/M_1 and S_1/M_1 , because of the relativistic nature of our calculation); ii) the effect of the spin-dependent part of the $q - q$ interaction, which is responsible for the $N - \Delta$ mass splitting and for the different high

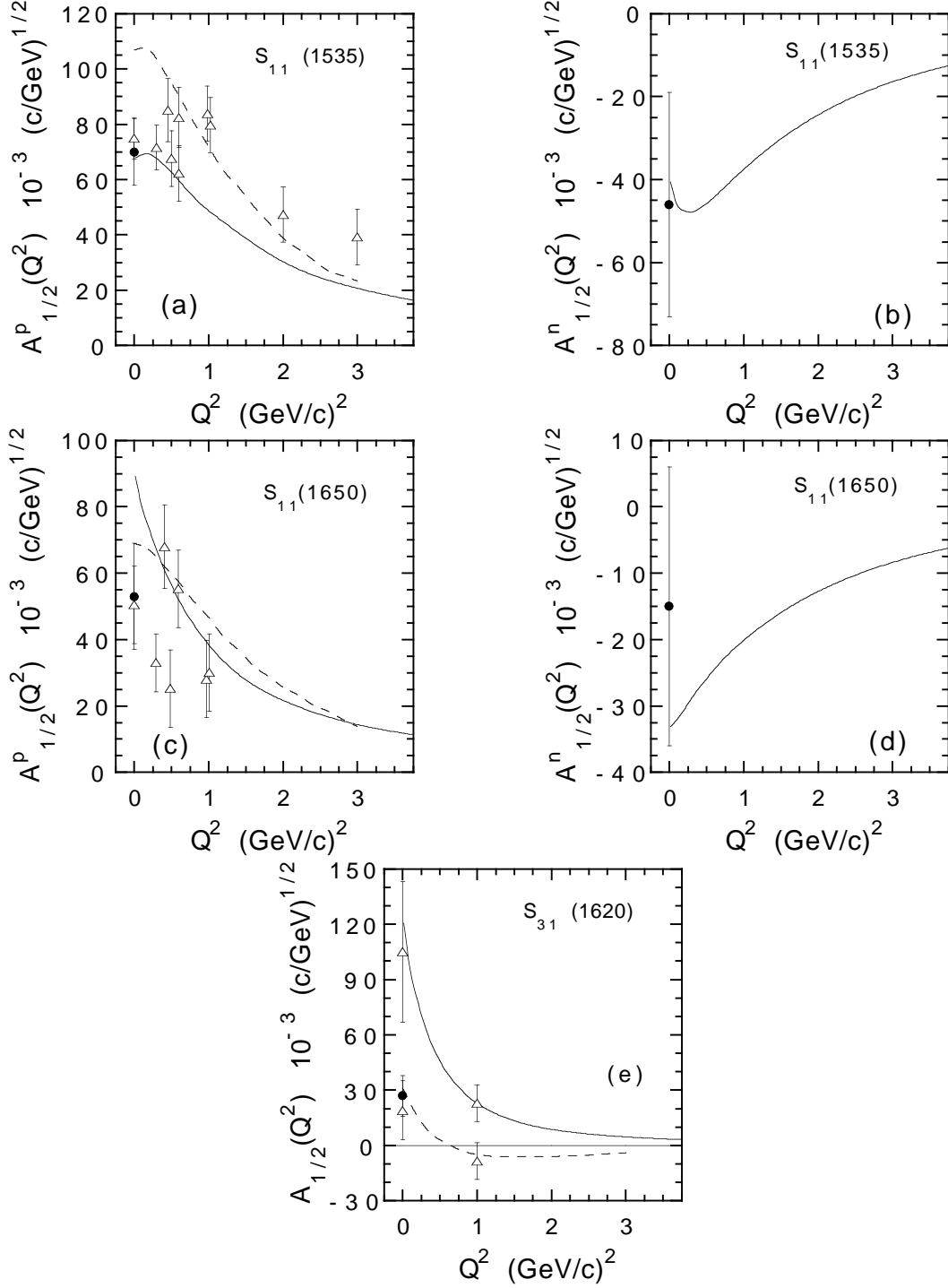


Figure 2. The transverse helicities $A_{1/2}^{p(n)}$ for the nucleon transitions $p \rightarrow S_{11}(1535)$ (a); $n \rightarrow S_{11}(1535)$ (b); $p \rightarrow S_{11}(1650)$ (c); $n \rightarrow S_{11}(1650)$ (d); $p \rightarrow S_{31}(1620)$ (e), vs. Q^2 . The solid and dashed lines represent our calculations and the results of a non-relativistic CQ model [6], respectively. Solid dot: PDG '96 [7]; triangles: data analysis from [8].

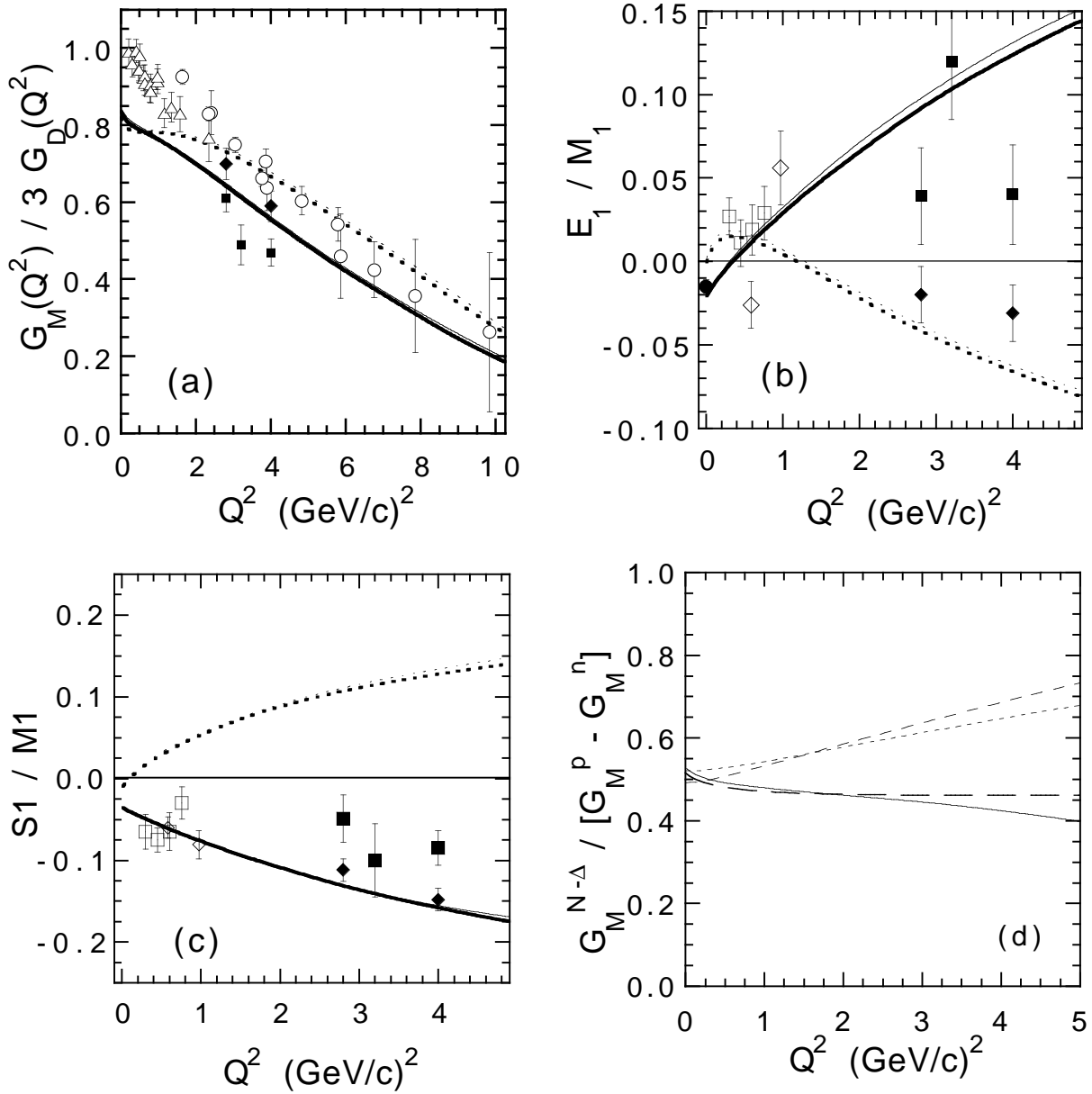


Figure 3. (a) The $N - \Delta$ transition magnetic form factor $G_M^{N-\Delta}(Q^2)/3G_D(Q^2)$, vs Q^2 . Solid and dotted lines are the results of prescriptions i) and ii) of Ref. [1](d). Thick and thin lines correspond to the full calculation with the CI interaction [3] and to the contribution of the S -wave in the Δ eigenstate, respectively. Triangles: Ref. [9](a); open dots: Ref. [9](b); full squares: analysis of Ref. [9](c); full diamonds: Ref. [9](d). - (b) The same as in (a), but for E_1/M_1 . Full dot: PDG [7]; open diamonds: Ref. [10](a); open squares: Ref. [10](b); full squares: analysis of Ref. [9](c); full diamonds: Ref. [9](d). - (c) The same as in (b), but for S_1/M_1 . - (d) The ratio $G_M^{N-\Delta}(Q^2)/(G_M^p(Q^2) - G_M^n(Q^2))$ vs Q^2 . Solid line: our calculation (prescription ii) of Ref. [1](d) with the CI baryon eigenfunctions and CQ form factors; dashed line: the same as the solid line, but without CQ form factors; short-dashed line: the same as the dashed line, but with the baryon eigenfunctions corresponding to the spin-independent part of the CI interaction [3]; dotted line: the same as the dashed line, but retaining only the confining part of the CI potential.

momentum tails of the N and Δ wave functions, is essential to reproduce the faster-than-dipole fall-off of $G_M^{N-\Delta}(Q^2)$ (see also Ref. [1](f)). Both these results do not depend on the prescriptions used to extract the $N - \Delta$ transition form factors.

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